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# LINK BETWEEN EXTERNAL ELECTROMAGNETIC FIELD AND BIOLOGICAL MATTER

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The effect of EMFs in biology is controversial, partly due to a lack of definition of a mechanism of interaction.

A shielding device is constructed to identify the effects of EMF inside the rat. The animal and recording system are shielded but not the tail, which is exposed to EMF. Veins and arteries function as relatively insulated conducting "cables." Results of these experiments are presented and conclusions drawn.

KEY WORDS: EMF effects, leaking organ capacitors, vascular conduction, VICC, interference of fields.

## INTRODUCTION

Electromagnetic fields from high-voltage power lines, visual display units and various electrical household appliances have been suspected to cause biologic effects. Various disorders have been related to specific organs or functional units such as skin,[1–11] eye,[12,13] musculoskeletal disorders,[14] pregnancy[15,16] and stress reactions.[17–20]

In an attempt to establish a correlation between external EMFs and various biological effects, epidemiological studies have been made and some correlations established.[21] In other studies[22–24] a possible correlation was thought to exist between work with visual display units (VDU) and seborrhoeic dermatitis, acne, rosacea and perioral dermatitis. Later on, common facial dermatoses were found but no specific dermatoses with possible relation to VDU exposure,[11] Dry skin and red eyes were more common than otherwise among those exposed to VDUs in another study.[25] Magnetic and electrostatic fields from VDUs were not found to be of any major importance for skin disorders when using both liquid plasma screens or cathode ray screens.[26] Specific tests with exposure of skin to VDUs were not found to produce any skin disorders.[27]

In an epidemiological study on 3745 persons[28] it was concluded that those exposed to VDUs had subjective skin symptoms more often than a non-exposed control population. Rosacea was the most common facial skin condition.

Health effects of environmental electromagnetic fields[28] were studied in 1170 persons exposed to work near radio antennae and radar installations. Neutrophil phagocytosis was enhanced in a low-intensity group, but was reduced significantly at relative high intensities. Visual reaction time was also prolonged and the scores of short-term memory tests were lower in some high-intensity exposed groups.

In the study of effects of low-power pulsed EMFs in soft tissue,[29] it was not possible to demonstrate any significant effect of the fields on healing or on chick embryo chorio-allantoic membranes. At the application of pulsed EMFs no increase could

be produced in the incidence of malformations in chick embryos.[30] Pulsed EMFs were shown to increase a growth regulating factor in the French bean plant.[31]

At a chronical exposure to rats to a 60 Hz field, statistically, insignificant differences appeared between field-exposed and sham-exposed rats in the food and water intake. But the growth pattern differed by a slight initial delay in the development of the exposed rats.[32]

Many reports suggest that at least one of the mechanisms of action of low-frequency pulsing EMFs is a favouring of $Ca^{++}$ movement into the cell.[33]

By the exposure of *Drosophila* to a 16 Hz magnetic field, a significant sex limited recessive lethal mutation occurred.[34]

A large number of contradictory findings in clinical, epidemiological and experimental studies have prompted discussions of the background of variables in research involving EMFs.[35] Critical comments were made[36] on the use of EMFs in many biological studies and, particularly, the lack of precise specifications of experimental conditions.

*Summary:* Scientific reports on possible biologic effects by EMF, suggest or reject, to about equal extent the idea that such effects occur. Clinical studies, epidemiological statistics and subjective complaints are often rather vague or influenced by non-relevant factors. Also various experiments are not always specific enough to give conclusive results of possible effects *in vivo*.

## AIM OF THIS STUDY

The critical point in all EMF-studies is the necessity to identify a mechanism of biologic interaction *in vivo*. Attempts will be made to make such an identification in rats. Introduced electrodes and cables present targets for induction. A model for differential EMF-shielding of small animals and recording system was therefore constructed. The results from rat studies were then checked in a simplified analogue to vessels of the rat.

## METHODS

Twelve white rats of 340 to 400 g were studied after intraperitoneal injection of 0.0016 × weight of animal in g., of a 30% Membumal solution.

The body of a 390 g animal, 23 cm of length, has a tail 19 cm long. It is provided with about 28 vertebral bodies. Anterior to the vertebral bodies is positioned a single artery and to each side a vein. The vessels are visualized in a postmortem angiogram of a rat by injection of a barium sulphate suspension into the aorta (Figure 1).

*An analogue to the vessels of the tail of the rat was built for technical studies and controls of the experiments in rats.*

The plasma of blood vessels are electrically conducting but surrounded by the relatively insulating walls.[37–38] The vessels therefore possess the capacity to serve as conducting receptors for field induction by external EMFs. A simplified vascular analogue to the vessels was built (Figure 2). It consists of a "tail" to be exposed to the EMF and connecting vessels in the "body" of the analogue with two platinum electrodes for recording of "intravascular" potential differences. The "vessel" consists of a transparent plastic (vinyl) tube (outer diameter 3 mm, inner diameter 1.8 mm) filled with a 0.9% NaCl solution.

*A box for the selective shielding of a rat or an analogue from external changing*

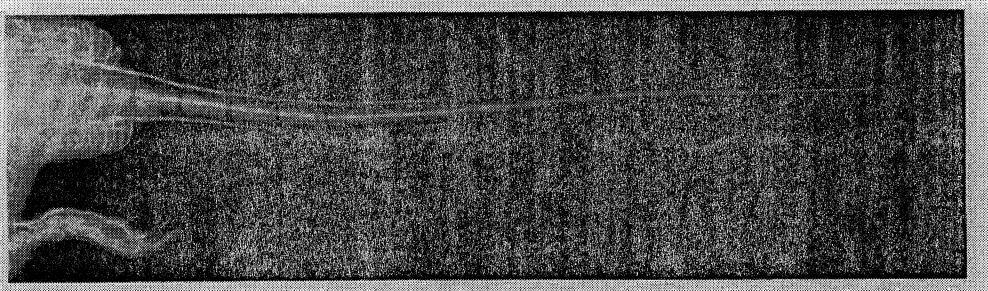

**Figure 1** Radiograph of a tail of a 390 g rat after postmortem injection of barium sulphate into the abdominal aorta. One artery is positioned anterior to the 28 vertebral bodies of the tail. At each side of the vertebral bodies are located a vein. The conductive plasma of blood is surrounded by the relatively high resistance of the walls of vessels. The vascular "cables" are primary targets for induction by external EMFs.

*EMFs* is made of layers of iron sheets giving a thickness of the walls of 2.5 cm (Figures 2 and 3). One side of the box is lower than the other ones and provided with a hole for the tail of the rat. It can therefore be taped on to the outer surface of the top cover of the box for selective EMF exposure. It is of importance that the inner walls, the walls of the hole for the tail and the outer surface of the top cover are insulated. The animal is thereby prevented from being grounded by unintentional contact with the metal. Grounding is not made of the reference electrode. In the wall, opposite the hole for the tail, another hole is made in the box for cables from the electrodes, previously implanted into the rat. The cables are led through a grounded tunnel of iron around the recording instrument. By making the tunnel long enough

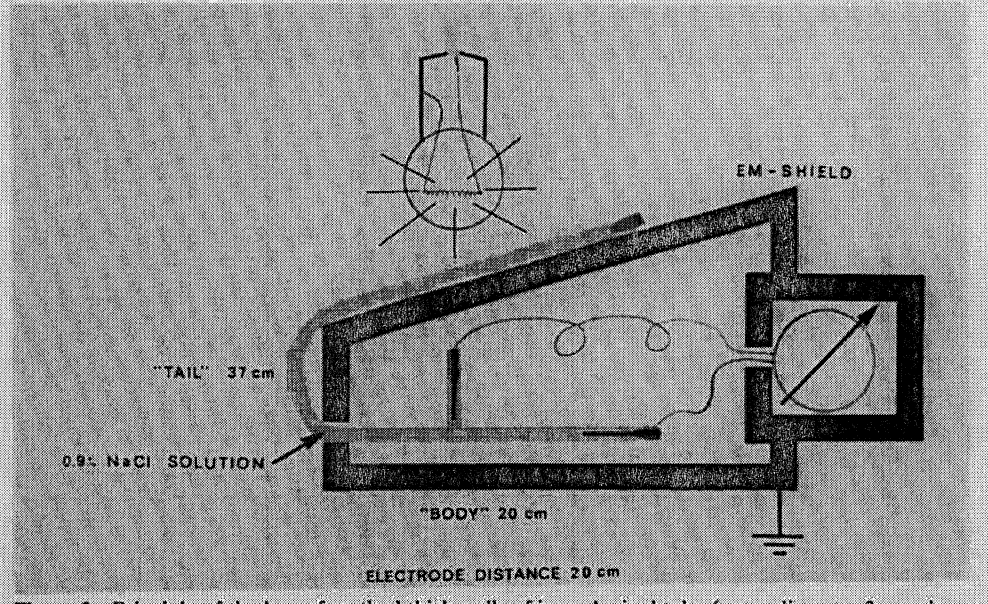


**Figure 2** Principle of the box of earthed thick walls of iron. A vinyl tube (outer diameter 3 mm, inner diameter 1.8 mm) filled with 0.9% NaCl solution simulates a conductive vessel of the tail and its abdominal connection in a rat. Two platinum electrodes in the "vessel" of the shielded "body" sense the induction in the vessel of the tail by the EMF of the powered lamp and its cable. Forking of the tube provided by a three-way stopcock, I.D. = 1.67 mm.

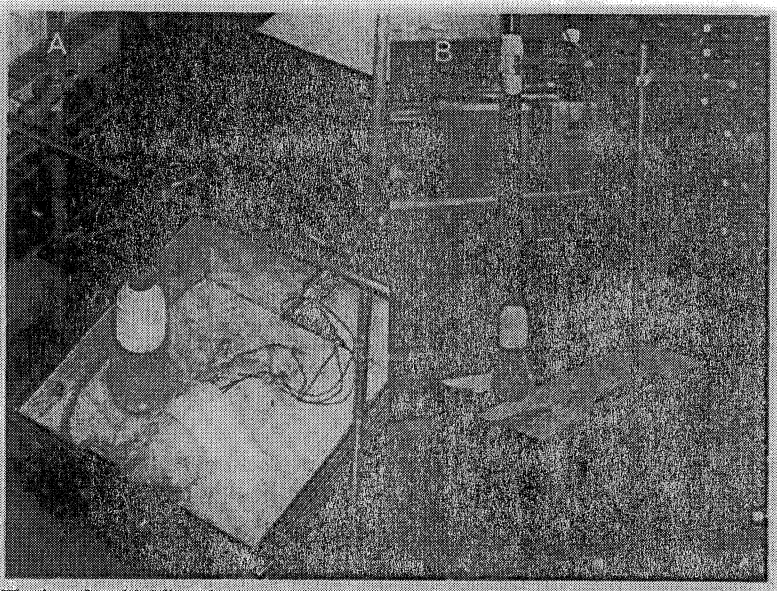


**Figure 3** The box for shielding the body of a rat, electrodes and cables from exposure of changing EMF of a powered light bulb, its socket and cable. Walls and top cover are 2.5 cm thick earthed iron. At the low side of the box a hole is made for the tail. The interior of the walls and the outer surface of the top cover are laminated with 2 mm thick vinyl sheets to protect the animal from being earthed. The hole for the tail has walls covered with electrically insulating tape. Cables from electrodes in the rat are shielded in a grounded iron tunnel between the box and the recording instrument, positioned 1 m away and surrounded by a cover of grounded iron. Box without top cover and the rat with electrode cables inside the box (A). The top cover in place (B) with the tail of the rat taped onto the insulated outer surface of the box. The light bulb is held by an adjustable stand. 1.2 m of the cable is surrounded by a 2.0 mm thick grounded iron tube.

(one meter) the thickness of grounded iron around the recording instrument can be kept moderately thick to shield the emitted EMF from a household light bulb and its powered cable.

*The efficiency of the shielding* of an actual EMF is tested by enclosing the entire animal in the box. The exposure of the box (at the later place of the tail) by the EMF source should then not induce any differences of voltage sensed by the recording system.

### *Electrodes and Recording Equipment*

Ag–AgCl electrodes were made from 0.2 mm Ag-strings, polished, chemically cleaned and covered with an AgCl layer by electrophoresis. The electrodes received a deposition of AgCl by 0.5 coulombs/cm$^2$. The soldered connection to the cables was insulated by shellack. Polyethylene tubes (Pe 500) were filled with 3 M KCl-agar. The bridges protruded 2 mm from the tip of the electrodes. In the vascular analogue polished platinum strings were used as electrodes.

Various locations of pairs of electrodes were tested. Via laparotomy electrodes were introduced into the left renal vein to the inferior vena cava or into the aorta via a femoral artery. One electrode was placed in the upper and one in the lower part of the peritoneal cavity and one in the subcutis of the right side of the abdominal wall. The electrodes were secured in their positions by ligatures.

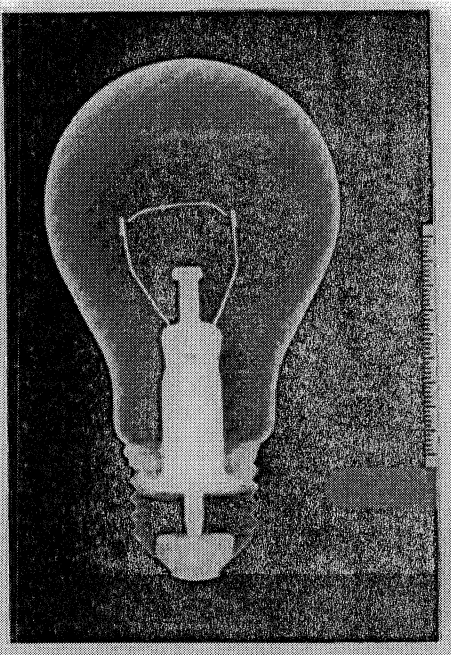

**Figure 4** Radiograph of a 60 W lamp bulb, 11 cm in length, has a base plate and the screw-shaped part for connection with the terminals in the socket. The coil of tungsten of the filament is 26 mm long and positioned 75 mm from the base plate and 30 mm from the top of the glass. Millimeter scale to the right.

*Recordings* were made with a Grass Bioelectric Instrument (Model 7P122) surrounded by a grounded metal cover. It was positioned one meter away from the fields to be tested. *Electromagnetic effects* from a 60 watt lamp and its supplying cable were studied.

The 60 W light bulb is of Philips® construction (Figure 4). Its filament is made as a coil of tungsten. The distance filament-top of glass of the bulb is 34 mm. The filament is connected to a base plate of the bulb and the screwshaped metal for the screw-shaped socket.

The lamp was powered by 220 V 50 Hz from a wall connection. Each of the terminals was powered by 110 V. A third was a connection for grounding.

The wires of the cable are individually insulated by a 0.5 mm thick layer of plastic with a common 0.5 layer around the two wires.

Each one of the wires of the cable was provided with a switch. The switches were located 3.5 m from the lamp and 1.5 m from the wall connection. Capacitative charging of the lamp and its cable 110 V from either one of the wires could thereby be obtained.

## RESULTS

1. *The EMF of an AC Powered Lamp Induced Oscillations of Voltage Recorded Deeply Inside the Rat*

Ag–AgCl electrodes in 3% KCl-agar bridges were introduced operatively into the aorta and into the peritoneal cavity of anaesthetized rat. The rat was placed on its

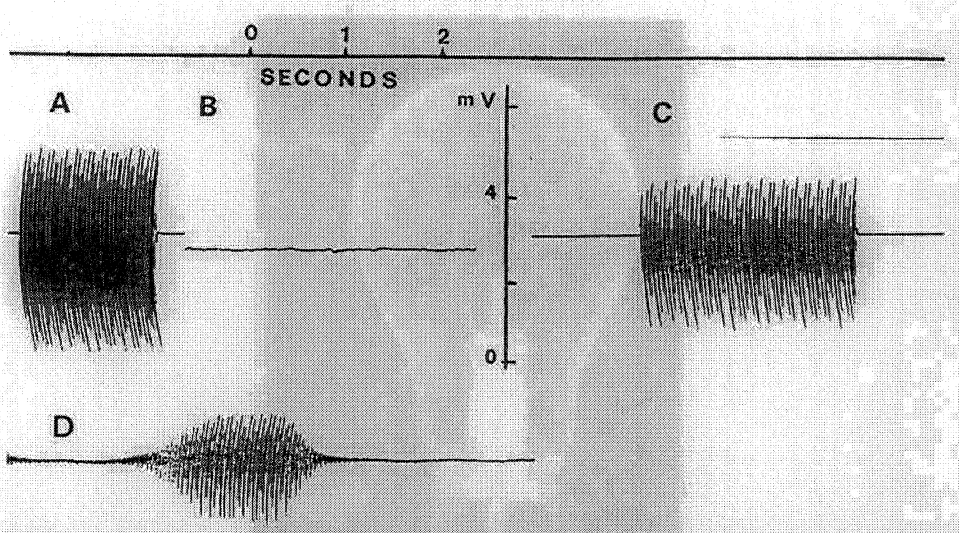


**Figure 5** A rat with Ag–AgCl electrodes in salt bridges in the aorta and the peritoneum is positioned in the box without top cover. A lighting 60 W lamp 10 cm above the animal produces irregular oscillations (A). With the same position of the lamp but the shielding top cover of the box interpositioned, no oscillations of voltage are recorded (B). The tail of the rat is pulled out of the side-hole of the box and taped onto the outer surface of the top cover. The lamp, 1 cm from the tail, induces oscillations of voltage, sensed by the shielded electrodes inside the body of the rat (C). After giving the animal 4 ml of Membumal, oscillations of voltage were also recorded in the dead animal 24 hours later. (D) The 60 W lamp was moved from 50 cm to 3 cm from the tail and back.

back in the grounded box of thick iron. The cables from the electrodes were placed inside the grounded tunnel of iron which was also connected to the iron cover of the Grass recorder. At positioning of a lighting 60 W lamp 10 cm above the lower part of abdomen of the unshielded rat induction was obtained in the rat or/and in the recording system inducing irregular oscillations of voltage (Figure 5A). The top cover, placed over the box, was then also grounded. The same position of the light lamp did not now produce any oscillations of voltage by induction in the rat, electrodes, cables or Grass recorder, indicating efficient shielding of the system (Figure 5B).

The tail of the rat was now taken out through the hole (with insulated walls) from the box of grounded iron. The tail was taped on to the also insulated outer surface of the top cover of the box. About 10 cm of the tail was available for exposure of the EMF.

The externally positioned tail was now exposed to the lighting 60 W light bulb with a distance of one cm between the glass of the bulb and the surface of the tail. The 220 V 50 Hz powering of the lighting lamp produced field induction in the tail of the rat sensed as irregular oscillations of voltage by the electrodes inside the animal (Figure 5C).

The rat was given 5 ml of Membumal. The tail of the animal was again exposed to a 60 W lamp 24 hours after its death. The lamp was moved from 50 cm to 3 cm above the tail and back. Irregular oscillations of potential could be recognized in the shielded animal between Ag–AgCl electrodes in the aorta and the peritoneal fluid (Figure 5D).

*Comments:* The testing of the efficiency of the shielding of the animal and the recording system is essential. It was regularly found that the exposure of the tail

taken out from the shielding caused potential oscillations between one electrode in a vessel and another in the peritoneum or in the subcutis of the animal. This also occurred in the dead rat. A physical transmission of the EMF from the lamp to the rat is therefore a reality.

2. *The EMF of the 60 W Lamp, its Socket and Cable*

The 60 W light bulb, hanging from the ceiling in the cable with the bulb one cm from the tail of the shielded rat, produced, when alight, potential oscillations recorded in the rat (Figure 6A). The 220 V 50 Hz field caused irregular oscillations. One of the supplying wires of the cable was switched off. The lamp did not light but the wire, not switched off, the lamp and distal part of the wire which was switched off were now powered 110 V. The oscillations of voltage recorded were more regular in appearance. The potential differences were of about equal magnitude with 110 V (Figure 6B), as previously with 220 V. The oscillations were of the same appearance and magnitude of voltage by switching on only the other wire 110 V (Figure 6C).

*The vascular analogue* of the rat was now placed with the "body" with electrodes inside the protecting box, while 10 cm of the "tail" was placed on the outside surface of the top cover. With the lamp one cm from the "tail" the lighting lamp caused irrregular oscillations of voltage (Figure 6D). By separate powering each of the wires (110 V) the oscillations were less irregular and the voltage differences even larger (Figure 6E+F).

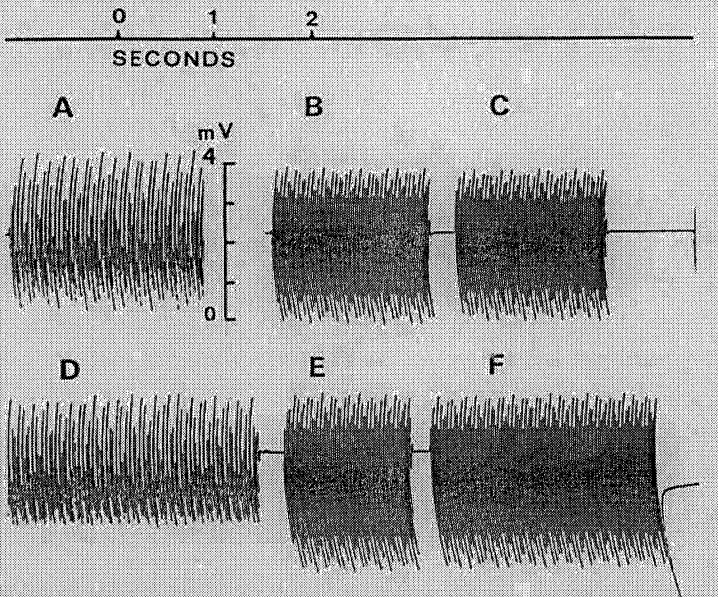


**Figure 6** A pattern of interference was produced by the field around each of the two wires of the 2 × 110 V, 50 Hz powered cable of the lighting lamp above the tail of the rat (A). When one of the wires, 3.5 m from the light bulb was switched off, the pattern of interference was decreased but the magnitude of voltage oscillations was almost the same at 110 V, 50 Hz capacitive charging of the non-lighting lamp (B and C). The analogue in the shielding box showed also irregular oscillation of potential by exposing its "tail" to the lighting 220 V powered light bulb (D). The pattern of interference decreased at switching of either one of the two wires of the cable powered by 110 V, 50 Hz. The voltage of oscillations increased (E and F).

### 3. *The Mechanism of Induction*

The powering of the bulb 220 V with flow of current through the lamp produces electric and magnetic oscillating fields. The electric field is capacitively transferred to the blood of conducting vessels inducing ionic separation, i.e. a voltage difference.

The electric field and its equipotentials around the two wires of the cable principally appear, as shown in Figure 7A. The magnetic field is principally induced, as shown in Figure 7B. The current is then flowing from the observer (+) and towards the observer (−). The magnetic field is enhanced between the wires. Around the wires the field is lowered. The oscillating flow of current produces oscillatory magnetic and electric fields. The electromagnetic field between the wires therefore exposes them to varying forces of mechanical displacements. Even minor spatial dislocations of the wires should result in changes of the surrounding electric and magnetic fields. The magnetic field induces secondary oscillating electric fields in the vessel, superimposed on the capacitively transferred primary electric field. The summation of the EMFs will induce effects on the ions when current is flowing in the wires. The resulting electric and magnetic fields represent gradients of flow. Depending on spatial location of ions, their magnitude of charge, size, mechanical resistance, etc, within the EMF, various dislocations (degree of polarization) will occur. Patterns of interference of voltage will be sensed by electrodes. Besides these

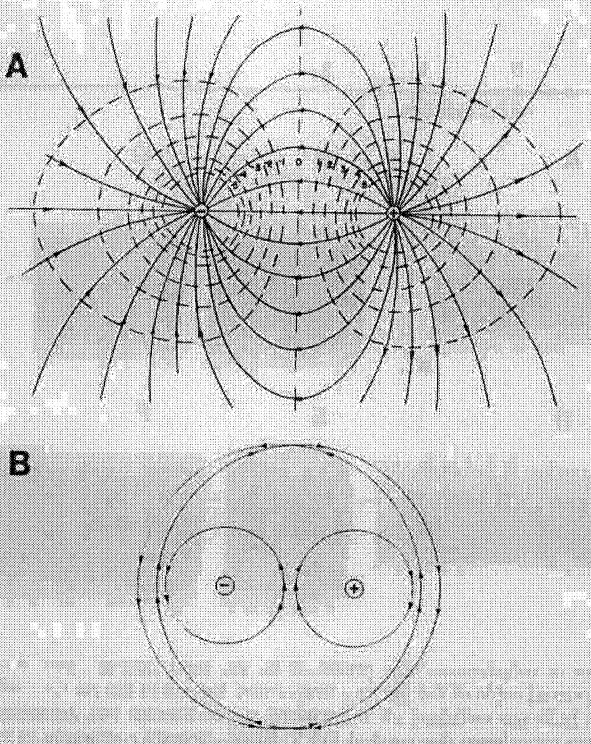


**Figure 7** Electric fields around two charged cables with their field lines and equipotentials (A). The principle of circulation of magnetic fields (B), induced by a flow of current in the direction from the observer (+) and towards the observer (−). Between the wires, the magnetic fields are enhancing each other. Around the cable they subtract their field strength.

functional effects, *the polarization of ions represent early expressions of molecular structuring of matter by the EMF.*

By only powering one wire 110 V up to the switch of the other wire, the oscillating 110 V field is changed by only the effect of minute capacitive flow of current leading to minimal electromagnetic induction at each phase. Virtually, only the electric fields are capacitively transferred from two cables to the vessels. The absence of magnetic fields therefore does not lead to interference with the capacitively transferred electric field. Stronger and less irregular ionic signals are induced by 110 V electrostatic powering as compared with 220 V closed circuit powering.

### 4. *The Possible Role of Heat and Light from a 60 W Lighting Lamp*

Ag–AgCl electrodes in KCl-bridges were inserted into the aorta via a femoral artery and into the peritoneal cavity of a 400 g rat. The rat and recording equipment were found efficiently shielded with grounded iron from the EMF of a 60 W lamp. The tail was taken out through the hole of the shielding box and taped onto the surface of the top cover. The 60 W lamp was positioned 2 cm above the tail. A glass partition, 15 × 40 cm large and 6 mm thick was inserted in the space of one cm between the lamp and the tail. At lighting the lamp (220 V) with the glass partition in place, oscillations of voltage were recorded larger in the animal (Figure 8A) than when the glass partition was removed (Figure 8B). When one or the other of the two wires of the cable of the lamp was powered (110 V) and the lamp was not lighting, the oscillations of voltage were also recorded larger with the glass partition interpositioned between lamp and tail (Figure 8D) than without any glass (Figure 8C).

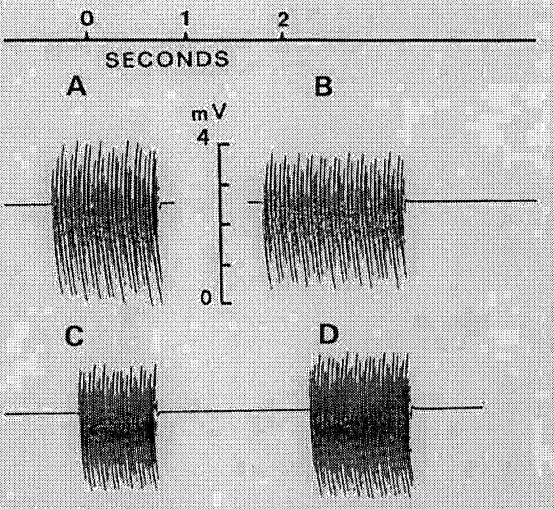


**Figure 8** Rat inside the shielding box. The tail was exposed to a lighting 60 W lamp, powered 220 V, 2 cm from the tail. Potential differences were recorded between electrodes in the aorta and the peritoneum. A 0.6 cm thick glass partition was inserted between lamp and tail. The irregular oscillations of potential were larger with interposition of the glass (A) as compared with no interposition of glass (B). By switching off either one of the two wires of the cable, a 110 V, 50 Hz powering of the (non-lighting) lamp was obtained. No interposition of glass produced less voltage of oscillation (C) than with interposition of 0.6 cm of glass (D). The interposition of the glass indicates that an enhancement of transmission of the EMF takes place by the glass. It also excludes that the heat of the lamp is responsible for the oscillations of voltage in these experiments.

When the light bulb was positioned in a cardboard box the light was excluded from reaching the tail. The presence or absence of light frequencies did not influence the magnitude of potential oscillations of 50 Hz recorded in the rat.

*Comments:* Heat and light from the 60 W bulb has not been found to influence the recorded potential oscillations. The enhancement of voltage by the interposition of glass as compared with air occurs because of the larger dielectric constant of glass and thereby capacitance to transfer electric field to the vessels.

5. *Selective Vascular Conduction (Figure 9)*

Voltage was measured between electrodes in the inferior vena cava and in the abdominal aorta. Another pair of electrodes was positioned in the peritoneal cavity and in the subcutis.

A lighting 60 W lamp was moved two times from 50 cm to 3 cm above the tail and back. This resulted in potential oscillations recorded between the vena cava and aorta (Figure 9A). When the lamp was switched off by unscrewing it two turns in its socket, the same movements of the lamp showed diminished differences of potential (Figure 9B). Simultaneous recordings of the potential differences peritoneal cavity-skin showed, with the lighting lamp, only waving potential differences which were synchronous with respiration (Figure 9C). These showed an irregular pattern with the lamp unscrewed (Figure 9D).

*Comments:* It was previously shown that arteries and veins have a cable-like function by the insulating properties of their walls around the conductive plasma of blood.[37,38] An EMF inducing a voltage in a blood vessel will therefore be sensed by electrodes in a protected position distant from each other in the vascular system. The long distance conductivity of subcutaneous tissue fluid is apparently not as efficient as the blood with its conducting plasma. Induction of potential differences in the extravascular tissue fluid could in any case not be sensed as potential differences between peritoneal fluid and subcutis of the body of the rat.

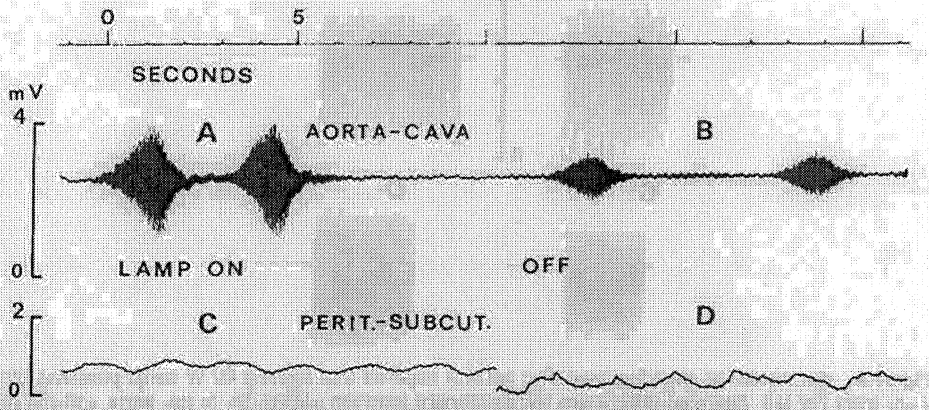


**Figure 9** The tail of the shielded rat was exposed by moving a 60 W lighting bulb from 50 cm to 3 cm from the tail and back two times. Voltage differences appeared between aorta-cava electrodes (A) but not between peritoneum-subcutis electrodes (C). By unscrewing the lamp two turns, the still powered socket of the non-lighting lamp induced voltage oscillations in the tail sensed by the vascular (B) but not by the extravascular electrodes (D). The socket is positioned about 4 cm more distant from the tail than the filament of the bulb which may account for the reduction of voltage. The wave-like slow and more rapid fluctuations (C and D) were synchronous with respiration and pulsations of the heart.

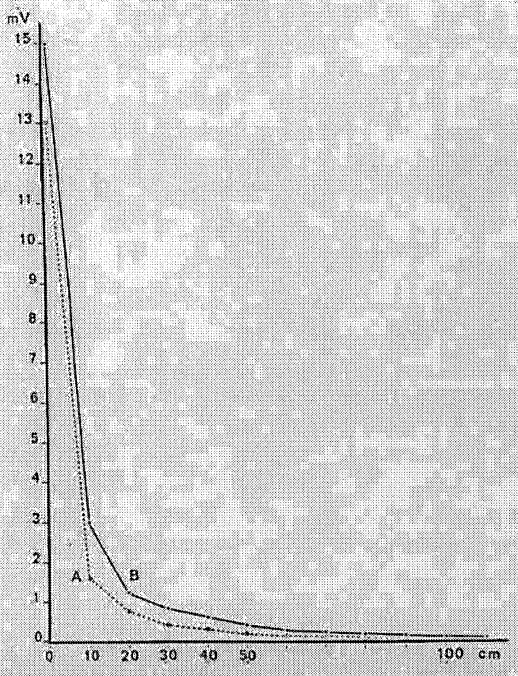


**Figure 10** Effect of distance to the tail of a rat and a non-lighting 60 W bulb with powered cable (A) and a lighting 60 W bulb. The bulb was hanging from the ceiling in its cable above the tail of a shielded rat. At 100 cm distance, the recording inside the animal between one electrode in the cava and one in the peritoneum shows almost no potential differences. They increase rapidly at a distance of 20–30 cm and are 13–15 mV with the glass of the lamp close to the tail.

The lighting lamp produced larger potential oscillations than the non-lighting, unscrewed lamp. In the first case the filament was activated, 3 cm from the glass and 6 cm from the tail. In the second case the socket, 10 cm from the glass is activated, 13 cm from the tail. These differences may account for difference of strength of the EMF.

6. *The Effect of Distance Between Tail of the Rat and a 60 W Light Bulb or its Powered Socket*

A 60 W light bulb was hanging on its cable 110 cm above the tail of a rat with its body and electrodes shielded in the box. The induction in the tail was recorded at 10 cm decreasing distances of the unscrewed, not lighting (Figure 10A) and the lighting light bulb (Figure 10B).

*Comments:* The differences between the lighting and nonlighting bulb are relatively small. The lighting bulb has a powered filament but the unscrewed bulb a powering of the terminals of the socket. This means a 4.5 cm longer distance for the socket as compared with the filament, which may account for some of the differences. On the whole, a lighting lamp or only the powered socket, including its distal part the cable, produce approximately comparable fields within a 100 cm distance. The recorded differences of potential are between 0.5 and 15 mV for the lighting bulb and between 0.25 and 13 mV for the socket at distances of 50 cm.

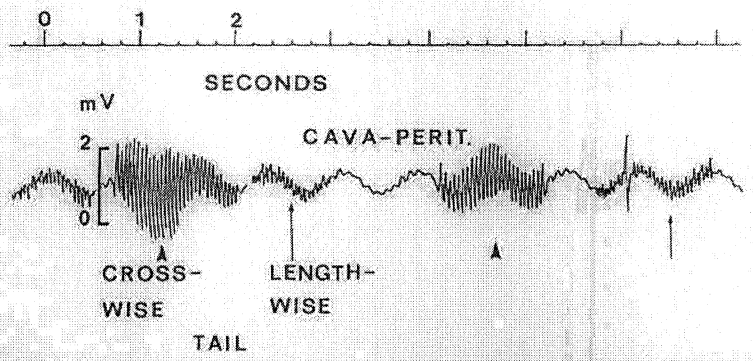


**Figure 11** The 220 V, 50 Hz powered lighting lamp is moved crosswise the tail of a shielded rat, which causes larger voltage oscillations than by moving the lamp lengthwise the tail. The slow fluctuations were synchronous with the respiration of the animal.

### 7. *The Effect of Crosswise and Lengthwise Movements of a Lighting 60 W Bulb Over the Tail of a Rat*

Potential recordings were made between one Ag–AgCl electrode in the inferior cava and one in the peritoneal cavity. The movements were made manually at holding on the proximal part of the light bulb. The glass of the bulb was moved about 2 cm above the tail. Crosswise movements caused larger potential fluctuations (arrowheads, Figure 11) as compared with lengthwise movements (small arrows, Figure 11). The wave-like fluctuations of the base-line were synchronous with respiration.

*Comments:* Induced potential differences in the tail are larger when the inductor moves towards and from the conductor, the vessels of the tail, as compared with movements along the conductor, all in accordance with the law of induction. This would mean that a moving external inductor will induce potential differences variably, depending on the spatial orientation of the conductor. Prerequisites are thereby present for induction of potential differences between different parts of the vascular system.

### 8. *The Body Consists of Orders of Variably Leaking Capacitors*

The exposure of the tail of the shielded rat and the recording system has indicated that induction takes place in the cable-like vessels of the tail. The potential differences are sensed by the selective conductive properties of the vessels. Other modes of transfer of external EMF to the rat may also be considered.

*The relatively insulating membranes of cells* surround their conductive content. They therefore mimic technical capacitors which are characterized by their time constant. A cell is, however, a variably, bidirectionally leaking capacitor due to its functionally varying ionic channels in its membrane.

Cells form larger *units such as organs* surrounded by electrically insulating fibrous capsules. Conductive, "leaking" communications exist with other organs via blood and lymph-vessels and nerves. Organs are therefore also variably leaking capacitors. This is virtually also the case with e.g. *the vascular system* which is built as a variably leaking capacitor with exchange of ions and water across capillary membranes.

*The whole body* is surrounded by relatively resistive skin with a content of conductive electrolytes in between organs and cells. The body is a leaking capacitor because of transport of water and electrolytes across the skin.

A capacitor can be charged from outside by electric field. These circumstances indicate that a variable degree of induction must occur, not only in structures such as the cable-like leaking capacitor of blood vessels, but also in the ease, for example, of the extravascular tissue, fluid and cells forming sub-components of variably leaking capacitors.

9. *Charging and Discharging Leaking Body Capacitors*

The body of the examiner was variably charged by EMF of a 220 V, 50 Hz cable. A powered 220 V cable or either one of the 110 V insulated wires of the cable was held by the left hand. Fingers of the right hand were used to transfer secondarily the EMF oscillations of the examiner to the tail of a rat or to the tail of the vascular analogue. The distance between the left and right hand of the examiner was 170 cm.

An examiner, wearing rubber shoes, is relatively separated from ground and can obtain a stronger oscillation of potential of the body than by wearing leather shoes.

The examiner, wearing rubber shoes, produced varying induction in his hand by making "contractions" with his left hand around the powered 110 V wire and held the right index finger onto the tail of a rat. The space between the surface of the hand and surface of the insulated wire was thereby varied. Oscillations of potential were transmitted through the examiner to the tail of the rat. The recordings were made between electrodes in the aorta and in the peritoneum of the rat (Figure 12A). After changing from rubber to leather shoes the voltage of potential oscillations were diminished (Figure 12B).

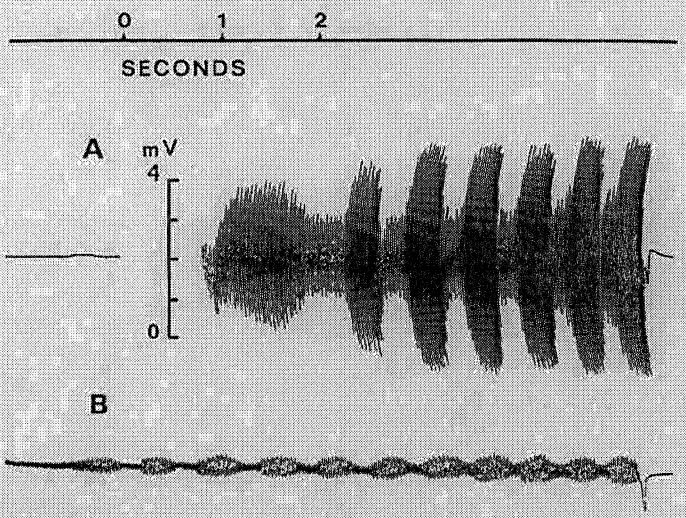


**Figure 12** The living body consists of orders of variably leaking capacitors. The examiner, wearing rubber shoes, makes rhythmic contractions of his left hand around a 110 V, 50 Hz powered wire while he holds the index finger of the right hand on to the tail of a shielded rat. Oscillations of voltage are recorded inside the rat between electrodes in the aorta and the peritoneum (A). After changing to leather shoes the voltage differences are considerably lower (B).

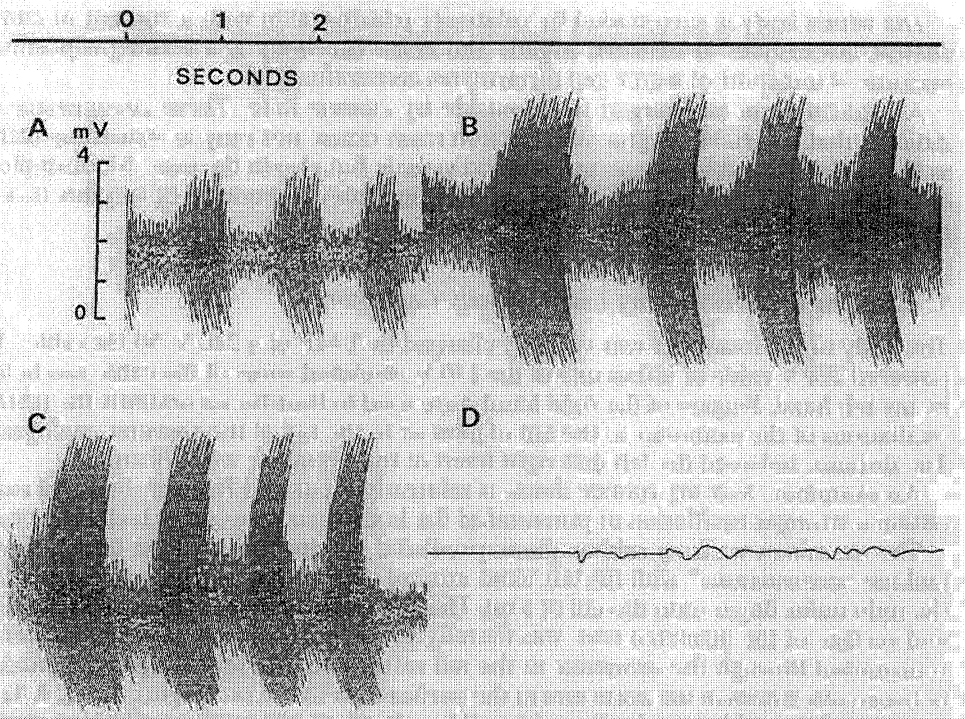


**Figure 13** The examiner, wearing rubber shoes, places his left hand around the cable of a 220 V powered lighting lamp. His right finger is placed on the "tail" of the analogue with the "body" shielded in the box. Potential differences are recorded between platinum electrodes in the analogue (A). By making contractions with his left hand around a 110 V powered wire of the cable and positioning a finger on the "tail" more regular oscillations and increase of voltage is recorded with one wire (B) or the other wire (C). When an earthed copper wire is wrapped around a finger of the left hand and contractions were made around the 110 V powered wire only small irregular variations of potential were recorded (D).

The "tail" of the analogue was then placed on top of the grounded box and the "body" shielded inside the box. Recordings of potential were made between platinum electrodes in the body of the analogue (Figure 13).

The examiner, wearing leather shoes, made with his left hand rhythmic "contractions" around the powered 220 V cable while his right index finger was leaning against the plastic tube of the "tail" of the analogue. Series of voltage oscillations were recorded via the analogue (Figure 13A). Contractions of the left hand around each of the powered 110 V wires of the cable resulted in larger oscillations of voltage (Figure 13B +C). When a grounded copper wire was wrapped around a finger of the left hand of the examiner and rhythmic contractions were made around one of the 110 V wires only small irregular potential variations were recorded (Figure 13D).

*Comments:* The inductive charging in the left hand is transmitted to the body of the examiner when wearing rubber shoes. He can further transmit his oscillating field to the analogue or to the tail of the living rat. Grounding of the examiner with a copper wire largely suspends the charging. This is partially also achieved when the examiner changes from rubber to leather shoes.

The charging and discharging of a subject is not only depending on a selective

induction of the blood in vessels. The degree of insulation of "the extravascular part of the body" of the examiner, e.g. by wearing rubber shoes or touching a grounded copper wire with his hand, clearly influences the secondary induction sensed by the shielded electrodes in the rat.

10. *The Effect of Contact with the Rat Tail by 1–3 Powered Fingers*

The examiner, wearing rubber shoes, held one of the 110 V wires of the powered cable in his left hand and placed 1–3 fingers onto the surface of the tail of the rat. The oscillations of voltage were recorded between aorta and peritoneum. They increased with the number of fingers placed on the tail (Figure 14A).

The analogue was then used with its "tail" on top of the box. One, two and three fingers were placed on top of the "tail." A similar effect with increasing oscillations of voltage was obtained with an increasing number of fingers (Figure 14B).

*Comments:* A larger surface area of EMF exposure leads to a larger voltage induction in the tail of the rat or its vascular analogue. In spite of the similar effects on the tail and on the vascular analogue, the mode of transmission of the EMF may partly be different. The vessels of the tail are surrounded by cells and tissue capacitors which can be charged in a way similarly to the charging of the finger capacitors of the examiner. The tissue components of the tail provide a larger area for field exposure than the rather narrow and deeply positioned vessels. Gradients of induced differences of voltage should therefore be induced among various cells and tissue regions.

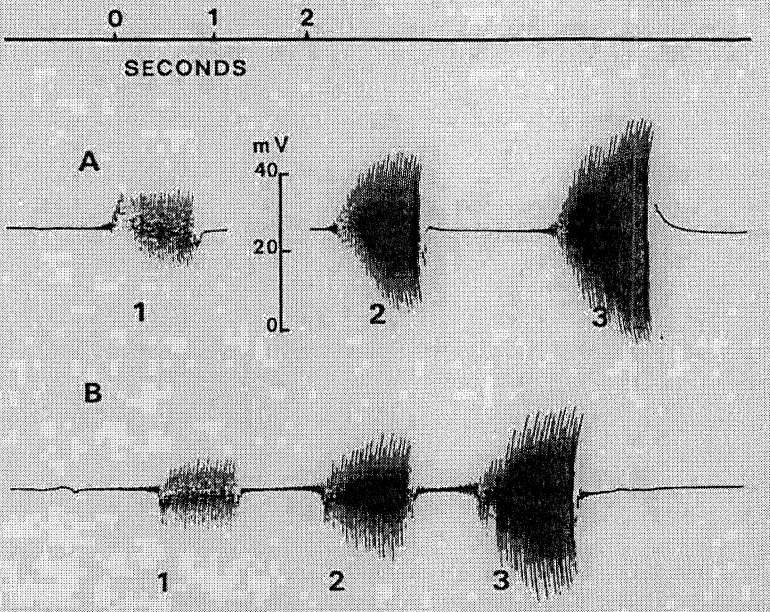


**Figure 14** The examiner, wearing rubber shoes, held on to one of the 110 V powered wires of the cable with his left hand and placed 1–3 fingers onto the surface of the tail of a rat. An increase of oscillations of voltage was recorded between Ag-AgCl electrodes in the aorta and peritoneum with numbers of fingers (1–3) placed on the tail (A). Similarly, the oscillations of voltage increased with the numbers of figures (1–3) placed on the "tail" of the analogue as recorded between platinum electrodes (B).

## GENERAL SUMMARY AND CONCLUSIONS

The linking of an external changing EMF and the interior of a biologic subject is demonstrated. For this purpose a "box" was constructed for shielding the subject, a white rat, implanted electrodes and cables. An extended shielding was also arranged for the cables and the recording equipment. The efficiency of the shielding can be checked and was found efficient for the shielding of a rat against EMF of a 60 W light bulb powered by 2 × 110 V, 50 Hz. A selective activation of the tail of the rat by the light bulb permits the identification of induction in the biologic material sensed by the protected electrodes and recording system. Heat and light of the lamp are excluded to cause this induction. Transfer of external EMF is enhanced by the interposition of glass. The body consists of orders of bidirectionally "leaking capacitors" such as cells, organs and the whole body which can separately and variably be charged. Also the vascular system functions as a leaking capacitor by its selective conduction of the blood plasma, circulating in the tubes of relatively resistive vascular walls. The vascular capacitor is "leaking" over the capillaries. A main target in the experiments are the large vessels (one artery and two veins) in the tail of the rat. The cable-like function of vessels, previously identified, is considered to function in the experiments on rats as primary targets for induction leading to intravascular ionic polarization. Due to the conductive properties of blood plasma, this effect is sensed by one intravascular and one extravascular electrode positioned in a shielded position inside the body of the animal. A support for this hypothesis is provided by the construction of a vascular analogue of the vessels of the tail and the body vessels of the rat. This analogue consists of a plastic tube, provided with two platinum electrodes in the "body part," is filled with 0.9% NaCl and is closed in its two ends. Used in the shielding box the "tail" was exposed to the EMF. Similar effects were obtained as in the living rat. In the living rat the extravascular isssue components must also become polarized under the influence of the EMF. This was simulated by charging the examiner by the EMF and the transmission of the oscillating EMF of his body to the "tail" of the analogue by one or several fingers. This way of transferring energy of the EMF leads to "secondary" activation of the vascular analogue. Correspondingly, the extravascular tissue components of the real tail of the rat may also become influenced by the process of induction in the blood plasma of the vessels of the tail. The degree of the recorded induction, sensed via blood plasma of the real tail and the "tail" of the analogue, is proportional to the surface area of exposure for secondary induction. The magnitude of induction in a blood vessel is depending on the direction of movement of the inductor in relation to the direction of the vessels. Thereby potential differences will appear among various vascular branches leading to secondary flow of current for levelling of voltage differences. This should predominantly occur over the previously described vascular-interstitial closed circuits (VICC).

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**References**

1. C. F. Walker, D. L. Seitelman, J. H. McElhaney, S. P. Mullen, B. Hagadorn and Y. J. Seto, "Effects of high intensity 60 Hz fields on bone growth" *J. Bioelectricity* **1**, 339–349 (1982).
2. M. Reichmanis and A. A. Marino, "Bioelectric considerations in the design of high-voltage power lines" *J. Bioelectricity* **1(B)**, 329–338 (1982).

3. V. Lindén and S. Rolfsen, "Video computer terminals and occupational dermatitis. *Scand. J. Work Environ. Health* **7**, 62–67 (1981).
4. A. Nilsen, "Facial rash in visual display unit operators" *Contact Dermatitis* **8**, 25–28 (1982).
5. H. H. Tjönn, "Report of facial rashes among VDT operators in Norway" **In**: (B. G. Pearce, ed.) *Health Hazards of VDTs?* (John Wiley & Sons, Chichester, UK, 1984) 17–23.
6. R. J. G. Rycroft and C. D. Calnan, "Facial rashes among visual display unit operators" **In**: (B. G. Pearce, ed.) *Health Hazards of VDTs?* (John Wiley & Sons, Chichester, UK, 1984) 133–15.
7. L. Feldmann and W. Eaglstein, "Terminal illness" *J. Am. Acad. Dermatol.* **12**, 366 (1985).
8. A. A. Fisher, "Terminal dermatitis due to computers (visual display units)" *Cutis* **37**, 153–154 (1986).
9. B. Stenberg, "A rosacea-like skin rash in VDU-operators" *In*: (B. Knave & P.-G. Widebäck, eds.) *Selective Papers from the International Scientific Conference: Work with Display Units*, Stockholm 12–15 May 1986. (Elsevier Science Publishers BV, Amsterdam, 1987) 160–164.
10. K. Matsunaga, R. Hayakawa, Y. Ono and O. Hisanaga, "Facial rash in a visual display terminal operator" *Ann. Rep. Nagoya Br. Hosp.* **22**, 57–61 (1988).
11. M. Berg, "Facial skin complaints and work at visual display units." *Diss. 1989, Stockholm. Acta Dermato-Venereologica Suppl.* 150 (1989).
12. K. G. Nyman, B. G. Knave and M. Voss, "Work with video display terminals among office employees. IV. Refraction, accommodation, convergence and binocular vision" *Scand. J. Work Environ. Health* **11**, 483–487 (1985).
13. C. S. Shen, S . B . Chiu, A. H. Wang and L. S. Ko, "Accommodational and visual fatigue in visual display terminal (VDT) work" *Acta Ophthalmol. (Copenh.)* **185** (suppl.), 175–176 (1988).
14. R. Arndt, "Working posture and musculoskeletal problems of video display terminal operators: Review and reappraisal. *Am. Ind. Hyg. Assoc. J.* **44**, 437–446 (1983).
15. M. K. Goldheber, M. R. Polen and R. A. Hiatt, "The risk of miscarriage and birth defects among women who use visual display terminals during pregnancy. *Am. J. Ind. Medic.* **13**, 695–706 (1988).
16. R. W. Tuthill, "Assessment of the literature on health effects related to work at video display terminals" *Report to the Massachusetts Department of Public Health, Boston* (Dept. of Health Statistics and Research, Massachusetts Dept. of Public Health, 1985).
17. B. G. F. Cohen, M. J. Smith and L. W. Stammerjohn Jr., "Psychological factors contributing to job stress of clerical VDT operators" **In** (G. Salvendy and M. J. Smith, eds.) *Machine Pacing and Occupational Stress* (Taylor and Francis, London, 1981) 337–345.
18. S. Cox and T. Cox, "Occupational stress and VDUs" *Occup. Health (London)* **38**, 89–91 (1986)
19. G. Johansson and G. Aronsson, "Stress reactions in computerized administrative work" *J. Occup. Behav.* **5**, 159–181 (1984).
20. S. C. Nemeth and C. M. Childress, "Video display terminals alleviating visual and physical stress" *J. Ophthalmol. Nurs. Technol.* **6**, 106–109 (1987).
21. W. E. Murray, C. E. Moss, W. H. Parr *et al.*, "Potential health hazards of video display terminals" *Cincinnati, Ohio, Public Health Service* 1981 (NIOSH Research Report, 81–129).
22. C. Lidén and J. E. Wahlberg, "Work with video display terminals among office employees" *Scand. J. Work Environ. Health* **11**, 489–493 (1985).
23. C. Lidén and J. E. Wahlberg, "Does visual display terminal work provoke rosacea" *Contact Dermatitis* **13**, 235–241 (1985).
24. J. E. Wahlberg and C. Lidén, "Is the skin affected by work at visual display terminals? *Dermatologic Clinics* **6**, 81–85 (1988).
25. E. Svensson and J. Svensson, "Långvarigt bildskärmsarbete gav lindriga hudbesvär—tendens till ökning vintertid (in Swedish), *Läkartidningen* **84**, 1843–1845 (1987).
26. D. Koh, C. L. Goh, J. Jeyaratnam *et al.*, "Dermatologic problems among visual display unit operators using liquid plasma display and cathode ray tube screens" *Abstract No. 120, International Scientific Conference: Work with Display Units*, Montreal (September 11–14, 1989).
27. G. Swanbeck and T. Bleeker, "Skin problems from visual display units; provocation of skin symptoms under experimental conditions" *Acta Derm. Venereol. (Stockh.)* **69**, 46–51 (1989).
28. H. Chiang, G. D. Yao, Q. S. Fang, K. Q. Wang, D. Z. Lu and Y. K. Zhon, "Health effects of environmental electromagnetic fields" *J. Bioelectricity* **8**, 127–131 (1989).
29. C. F. Cullen, C. E. Wigzell and C. W. Evans, "Effects of low-power pulsed electromagnetic fields in soft tissue" *J. Bioelectricity* **8**, 47–58 (1989).
30. B. F. Sisken, I. Fowler, C. Mayaud, J. P. Ryaby, J. Ryaby and A. A. Pilla, "Pulsed electromagnetic fields and normal chick development" *J. Bioelectricity* **5**, 25–34 (1986).
31. D. B. Jones, G. P. Bolwell and G. J. Gilliatt, "Amplification, by pulsed electromagnetic fields of plant growth regulator induced phenylalanine ammonia-lyase during differentiation in suspension cultured plant cells" *J. Bioelectricity* **5**, 1–12 (1986).
32. Y. J. Seto, S. T. Hsieh, D. Majeau-Chargoid, W. P. Dunlap and J. R. Lymangrover, "Food consumption, water intake and growth data on rats, chronically exposed to a high-intensity 60 Hz field" *J. Bioelectricity* **2**, 197–205 (1983).

33. G. Emilia, G. Torelli, G. Ceccherelli, A. Donelli, S. Ferrari, P. Zuccini and R.. Cadossi, "Effect of low frequency pulsing electromagnetic fields on the response to lecitin stimulation of human normal and chronic lymphocytic leukemia lymphocytes" *J. Bioelectricity* **4**, 145–161 (1985).
34. J. M. R. Delgado, "Biological effects of extremely low frequency electromagnetic fields" *J. Bioelectricity* **4**, 75–91 (1985).
35. R. Becker, "Variables in research involving electromagnetic bioeffects" Letter to the Editor *J. Bioelectricity* **2**, 213–216 (1983).
36. W. C. Parkinson, "Comments on the use of electromagnetic fields in biological studies" *Calcif. Tissue Int.* **37**, 198–207 (1985).
37. B. E. W. Nordenström, *Biologically Closed Electric Circuits: Clinical, Experimental and Theoretical Evidence for an Additional Circulatory System* (Nordic Medical Publications, Stockholm, 1983) 1–358.
38. B. E. W. Nordenström, "An additional circulatory system: Vascular-interstitital closed electric circuits (VICC)" *J.Biol. Phys.* **15**, 43–55 (1987).